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Recent Developments in Fiber Radio Optical Transmitters

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Abstract – *This paper provides an overview of recent microwave photonic vector modulation (MPVM) work that can be used in several microwave applications including fiber radio transmitters. The MPVM theory of operation is presented along with proof-of-concept experimental results. The workshop presentation will include the latest results from ongoing experiments.*

Index terms *–fiber radio, direct carrier modulation, vector modulation.*

I. INTRODUCTION

In a typical digital communications transmitter data is modulated onto a low frequency intermediate frequency (IF) carrier prior to up conversion as shown in Figure 1a. Common IF carrier frequencies for radar and communications systems are 70 and 140 MHz. Multiple up conversion stages are often required to allow for practical filter implementation and to avoid undesired mixing products due to the low IF frequency. Recently, there has been a renewed interest in the use of direct carrier modulation for commercial wireless transceivers [1]. In direct carrier modulation the data modulates the desired microwave carrier frequency as shown in Figure 1b. Direct carrier modulation has the potential to simplify transmitter design by eliminating the need for multiple up conversions and their associated filtering requirements. Over the last decade, numerous monolithic microwave integrated circuits (MMICs) have been developed to support direct carrier modulation [2-5]. Many of these MMICs are based on the IQ or vector modulator approach. While M-ary PSK modulation ranging from QPSK to 256 QAM, data rates ranging from several Mbs to several hundred Mbs, and carrier frequencies from 1-110 GHz have been reported, many circuits were designed for a fixed operating band and data rate. Recently, the authors have been exploring a technique called microwave photonic vector modulation (MPVM) that utilizes the inherent bandwidth of photonics to simultaneously support multiple modulation formats, wide modulation bandwidth, and wideband tunability of a high frequency carrier. This MPVM approach may be used in high performance transmitters for microwave and millimeter wave communications systems and test equipment and is directly compatible with fiber radio applications [6].

II. MPVM APPROACH

An ideal vector modulator should be able to generate any constellation point in the signal space of the desired modulation scheme. This can be accomplished by decomposing the constellation point into two orthogonal vectors. For example, Figure 2 shows how the constellation points of a 16-QAM signal may be obtained by properly weighting and summing an in-phase (I) and quadrature (Q) component of the carrier signal. In general, the ideal vector modulator has the following requirements: 1) the carrier frequency must be split into I and Q components; 2) the I and Q components must be independently weighted to achieve the proper vector lengths; 3) the I and Q components must be bi-phase modulated to allow for 4-quadrant operation; 4) the weighted I and Q vectors must be summed to produce the desired resultant vector. Figure 3 shows a generic vector modulator block diagram that meets these requirements.

In the MPVM the decomposition of the carrier frequency into I and Q components is done in the microwave domain using a 90-degree hybrid power divider. The amplitude and phase balance are critical divider specifications that affect the vector modulator performance. The bi-phase amplitude modulation functions shown in Figure 3 may be realized using a pair of Mach Zehnder Modulators (MZMs). Bi-phase modulation is achieved by dynamically switching an MZM bias between $V\pi/2$ to $3V\pi/2$ as shown in Figure 4. In this manner, the I channel vector can be set to either 0 or 180 degrees while the Q channel vector can be set to either 90 or 270 degrees, thereby supporting full four-quadrant operation. The amplitude modulation may be achieved in one of two ways. First, the microwave drive level to the MZM may be adjusted using electronically programmable attenuators [7] or variable gain amplifiers. Unfortunately, this approach often has modulation bandwidth and carrier tunability limitations associated with the electronic control components. Alternatively, an all-optical approach may be used by dynamically switching the optical drive level at the input of the MZM performing the bi-phase modulation. Adjustment of the optical power to the MZM may be obtained in several ways including the use of a series MZM as an intensity modulator [8], the use of a series electroabsorbtive (EA) modulator, or direct modulation of the laser source. The use of the all-optical approach is attractive since switching rates of greater than 1 Gbs are easily obtainable with photonic components. The vector summation is done by combining the I and Q channels in a 3 dB optical power combiner prior to high-speed photodetection. It also can be noted that from the examination of QPSK, 8-PSK, and 16-QAM constellation diagrams that only binary MPVM control signals are required. The combination of fast switching speed and simple control signal requirements means that extremely fast (>1Gbs) data rates can be supported by the all-optical MPVM.

III. MPVM EXPERIMENTAL RESULTS

Several proof-of-concept MPVM experiments have been performed [7-8]. The most recent uses an all-optical control approach shown in Figure 5. MZMs 1 and 3 provide the intensity modulation for vector length modulation while MZMs 2 and 4 provide the required bi-phase modulation. This system was designed to operate over the 1–2 GHz band which was chosen based on available components and measurement equipment. A careful calibration procedure that involves both amplitude balance and delay equalization of the MPVM I and Q channels is necessary in order to achieve the best performance. The amplitude balance calibration ensures that the nominal vector lengths of the I and Q channels are identical. This is easily accomplished by monitoring the I and Q channels independently and adjusting the laser output power in one arm to achieve identical I and Q microwave output signal levels. The delay equalization calibration ensures that the total time delay of the I and Q channels are identical, thus allowing wideband operation. This is achieved using the I channel as a reference and measuring the differential delay of the Q channel with a microwave network analyzer. Fiber can be added to the appropriate channel to equalize the delays to within a fraction of a microwave wavelength. A microwave line stretcher can then be used to complete the delay equalization. Using this technique, an amplitude and phase balance of +/- 0.15 dB and +/- 0.65 degrees respectively was obtained at the calibration frequency of 1.5 GHz. The worst-case phase error in the 1-2 GHz band was +/- 2.0 degrees at 1.95 GHz and the worst-case amplitude imbalance was +/- 0.47 dB at 1.90 GHz. Figures 6a and b show the results of the calibration over the 1-2 GHz band.

The system performance was measured using an Agilent 89441A Vector Signal Analyzer to measure the error vector magnitude (EVM). The EVM provides a measure of the deviation from the ideal constellation point [9]. A 2^{23}-1 pseudo random bit sequence was used as a data sequence. Measurements were taken at several points over the 1-2 GHz band to demonstrate wideband capability of the MPVM. The data rates in these particular experiments were limited to several Mbs by the MZM drivers. Figure 7 shows a constellation diagram and spectrum for a data rate of 1 Mbs 16-QAM signal at a carrier frequency of 1.5 GHz. The measured EVM is 5.1%. Figure 8 shows the constellation diagram and spectrum for a data rate of 0.5 Mbs QPSK signal at the same carrier frequency. The measured EVM is 4.1%. The measured EVM for the QPSK signal as a function of carrier frequency is shown in Figure 9. The QPSK EVM is under 4.5% throughout the 1-2 GHz band. The EVM performance degrades rapidly as the carrier frequency is tuned out of the band as evidenced by the 10.6% EVM at 2.2 GHz. This degradation is due to the amplitude and phase imbalance of the microwave power divider. The imbalance can be seen in the skew of the constellation diagram as shown in Figure 10.

IV. CONCLUSIONS

This paper provides an overview of recent MPVM work. The MPVM can simultaneously achieve wideband carrier frequency tuning and high modulation bandwidths via the exploitation of the inherent bandwidth of photonic components and the microwave photonics approach is compatible with emerging fiber radio applications. While the experiments performed to date use multiple MZMs, an integrated optics version of the MPVM can provide enhanced performance, lower cost, and smaller size. An single integrated optics implementation of the MPVM that could support full vector modulation is proposed in Figure 11. The workshop presentation will include experimental results from ongoing efforts to demonstrate higher modulation speed as well as a discussion of several other design issues such as spectral shaping, dispersion issues, and loss.

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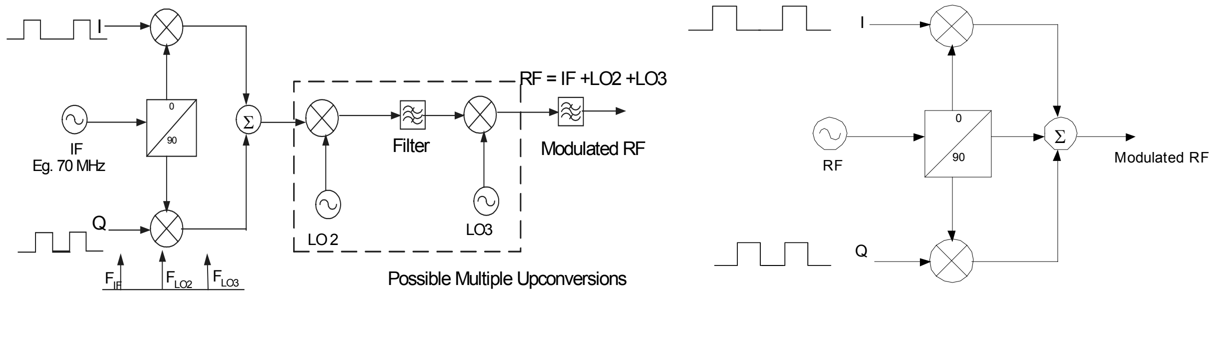
FIGURES



(a) (b)

Figure 1. Microwave Transmitter Configurations

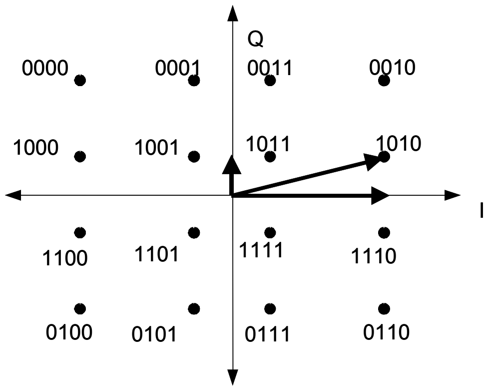


Figure 2. 16-QAM Signal Constellation showing IQ decomposition

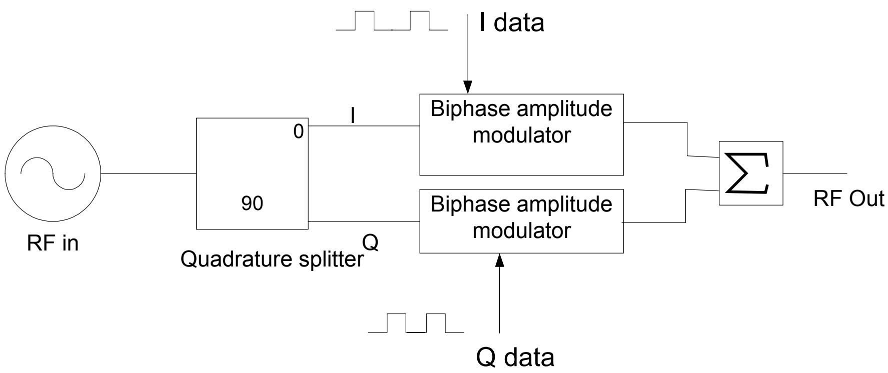


Figure 3. Generic Vector Modulator

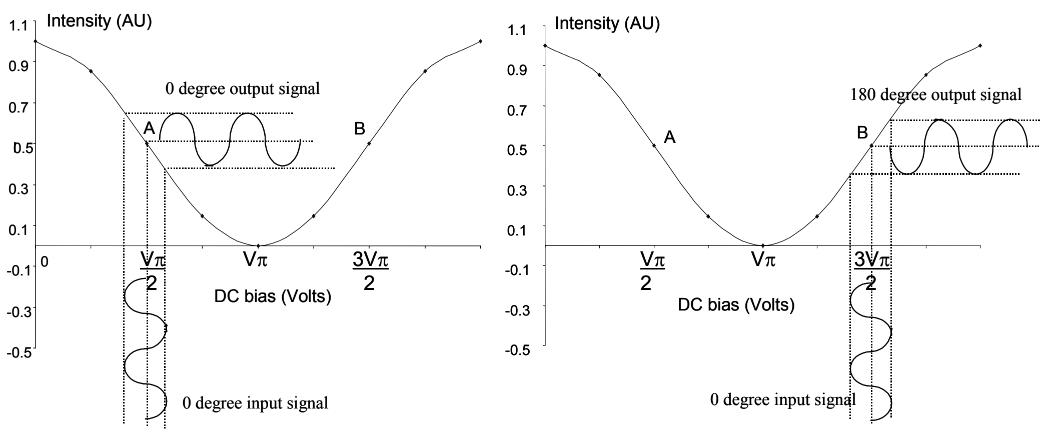


Figure 4. MZM Bias Switching to Achieve Bi-Phase Modulation

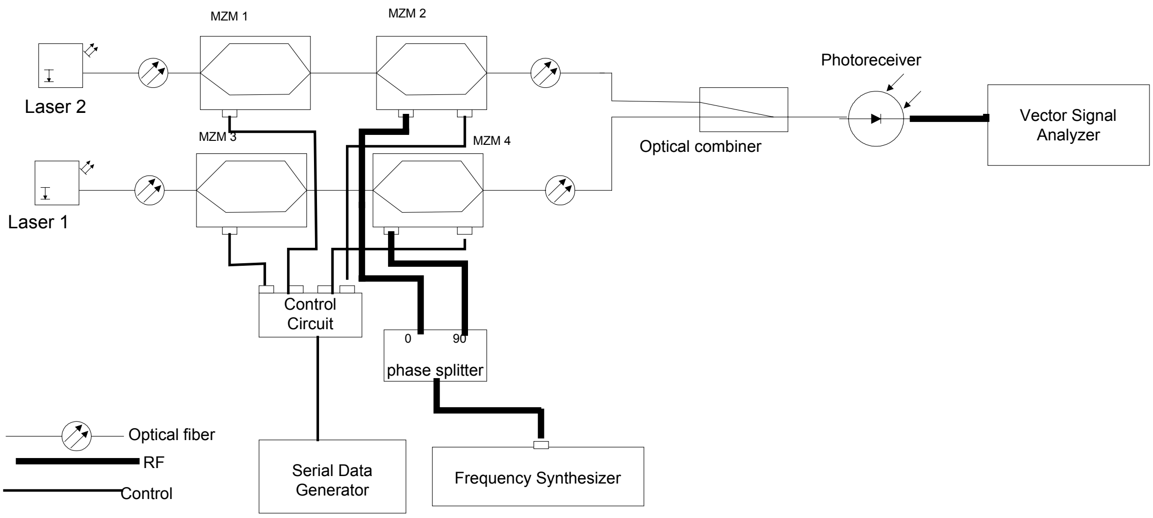
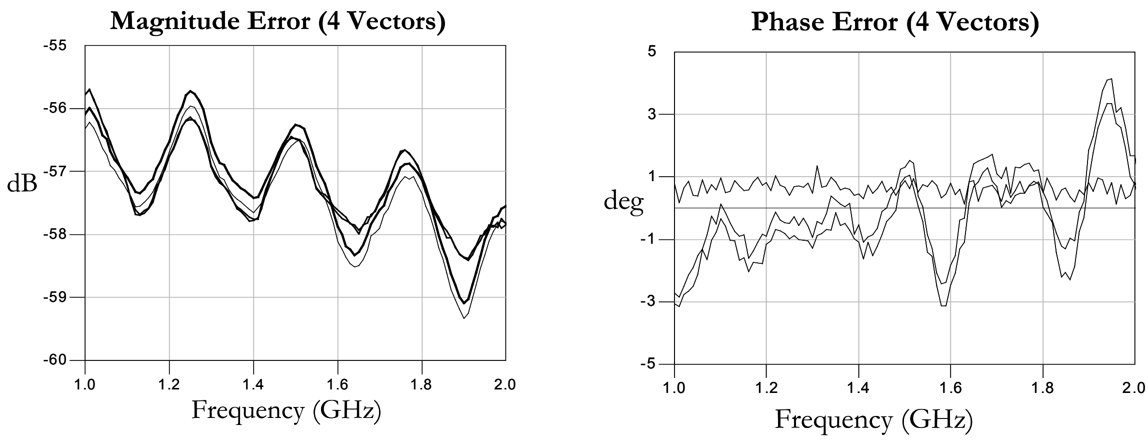


Figure 5. MPVM Block Diagram



(a) (b)

Figure 6. MPVM Calibration Results

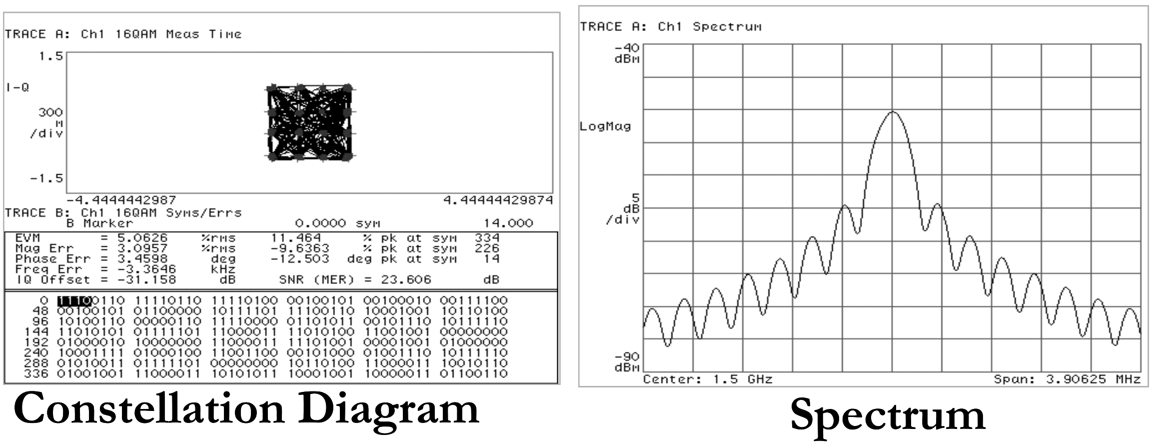
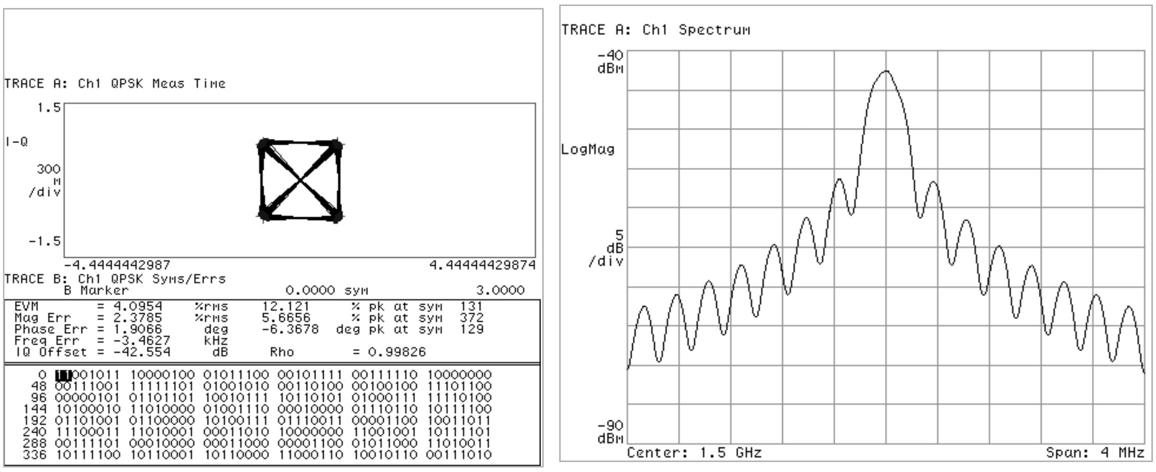


Figure 7. 16-QAM Constellation Diagram and Spectrum at f_c = 1.5 GHz



Constellation Diagram **Spectrum**

Figure 8. QPSK Constellation Diagram and Spectrum at f_c = 1.5 GHz

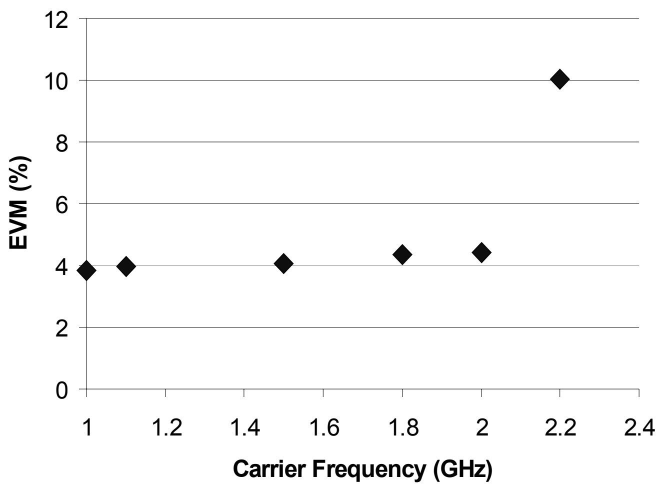


Figure 9. QPSK EVM vs. Frequency

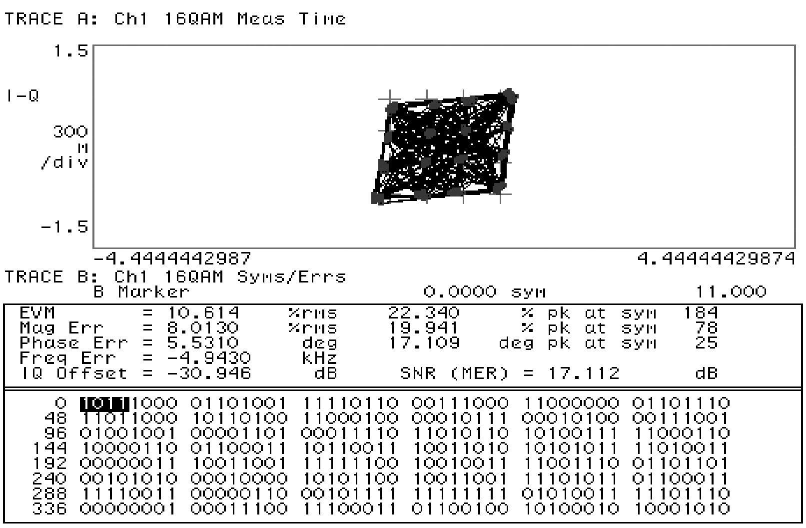


Figure 10. Out-of-band (2.2 GHz) 16 QAM result showing power divider imbalance

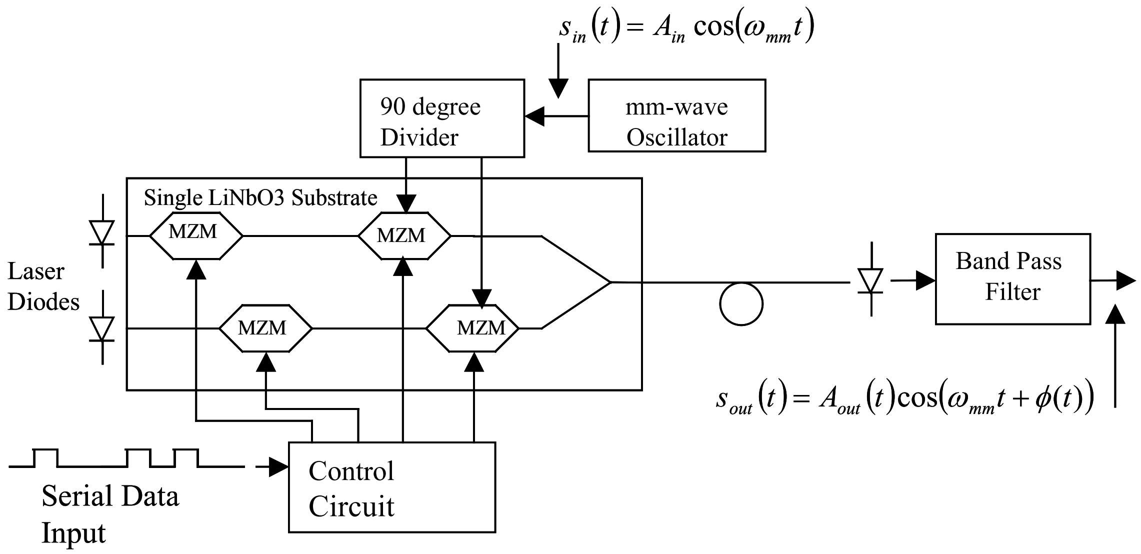


Figure 11. Integrated Optics MPVM Approach